case" results inasmuch as the test did not take into account substantial attenuation of the radar signal by trees, other vehicles, guard rails, buildings, diffraction losses, and ground scatter. It was also the case that during the tests, the main beam of the SRR antenna was aimed at the RAS receive antenna. The study, at Table 1, Page 10, concludes that separation distances of between 15 and 39 kilometers are called for in order to provide complete protection under the worst case for the Kitt Peak observatory. But the Kitt Peak antenna is sited such that it has a line-of-sight path to the City of Tucson, Arizona, which is not typical of RAS sites. As well, at Page 15 of the Study it is stated that "[m]itigation factors such as any terrain shielding, orientation of the transmitter antenna with respect to the observatory, or attenuation of the transmitter if mounted behind the vehicle bumper have not been taken into account, and would tend to reduce the avoidance radius."

32. In a Spectrum Planning Discussion Paper (SPP 2006-11) dated December, 2006 released by the Australian Communications and Media Authority entitled *Planning of the 71-76 GHz and 81-86 GHz Bands for Millimetre Wave High Capacity Fixed Link Technology,* there was an extensive discussion of the effects of foliage and vegetation loss as well as penetration loss in the millimeter-wave spectrum near 70 GHz. This document shows that the foliage losses near 70 GHz are "significant." Where foliage depth is 10 meters, for example (which is roughly equivalent to a large tree or two in tandem) the foliage loss is approximately 50 dB. Similarly, when millimeter-waves are propagated through various materials, they are more or less strongly attenuated.

33. Given the high degree of attenuation through free-space path loss, atmospheric absorption loss, and foliage and penetration attenuation applicable at 79 GHz, it is suggested that the actual interference contour around any of the few

radioastronomy observatories due to automotive SRRs is predictably very low. Given this, and given the fact that the observatories can, through the use of constructed shielding and the inherently remote siting of their antennas, reduce to a manageable level any interference potential from SRRs without any regulatory constraints placed on SRRs. It is not possible to utilize GPS-based or manual on-off switching of SRR systems due to the need of motorists to have the systems operational at all times while the motor vehicle is operating, and it is not necessary or desirable to interpose any such regulatory limits on SRRs because of the low predicted interference potential.

34. Bosch and the 79 GHz Project are committed to continuing to work with the RAS community in order to insure that there is compatible sharing of the 79 GHz band and that there will be no adverse effect on millimeter-wave experiments at any of the Radioastronomy observatories as the result of SRR deployment at 79 GHz. However, it is anticipated that there will be very few, if any, instances of interaction between SRR and RAS systems, and that the Commission, in Docket 11-90, speaking of changes proposed in the Part 15 rules governing automotive radar operation at 76-77 GHz, was correct in its assessment that "there is very little likelihood that vehicular radar systems operating at either the current or proposed limits would cause harmful interference to radio astronomy equipment."[28]

VI. Compatibility with the Amateur Radio Service (ARS)

35. For all of the same reasons that Bosch and the 79 GHz Project are confident that there will be little or no interaction between SRR operation and the RAS, it is highly likely that there will be little or no interaction between SRR operation at 77-81 GHz and

[28] *Notice of Proposed Rule Making* in ET Docket Nos. 11–90 and 10–28, FCC 11–79, released May 25, 2011, 76 Fed. Reg. 35176-35181, at paragraph 14.

the Amateur Radio Service in the same frequency range, and no constraints will result to Amateur Radio operation in the band. As noted hereinabove, the Amateur Radio Service (and the Amateur-Satellite Service) has a primary allocation at 77.5-78 GHz in the United States, and secondary allocation status in the remainder of the 77.0-81 GHz band. Notably, the primary allocation in the United States (i.e. within ITU Region 2) to the Amateur Service is *not* harmonized with the CEPT allocation (ITU Region 1) for the Amateur Service at 75.5-76 GHz. A harmonized allocation would permit Radio Amateurs in both ITU Regions increased availability of equipment for use in this band, and it would promote the sharing of experimental operating information and techniques among United States radio Amateurs and their brethren in ITU Region 1. Of concern in making available the 77-81 GHz band for automotive SRR operation in the United States is the presumed incompatibility between vehicular radars and Amateur Radio operations in the range 76-81 GHz. The Commission has in the past assumed that there is an incompatibility between Amateur radio terrestrial and satellite operations and vehicular radars due to the difficulty in coordinating mobile SRR operations with the unpredictable fixed, mobile and temporary fixed Amateur Radio operations that could occur in a shared millimeter-wave band in close geographic proximity to vehicular radars. The ECC, in ECC decision of 19 March, 2004 [ECC/DEC/(04)03], found in essence the same incompatibility: "that use of SRR within the band 77-81 (sic) may be incompatible with the Radio Amateur Service which has been resolved by allowing the Amateur Service to remain in the 75.5-76 GHz band after 2006 (see footnote 5.559A)." There is no such provision in the United States, however; the Amateur Service allocation at 75.5-76 GHz was deleted in 2003 in ET Docket 02-146.[29]A substantial justification for the deletion of

[29] That proceeding was intended to implement WARC-92 and WRC-2000 Final Acts. With respect to the

that allocation for the Amateur Service was that there was available spectrum at 77-81 GHz for Amateur operation.[30] Furthermore, the Amateur Service allocation at 76-77 GHz was effectively deleted because of the presumed incompatibility with vehicular radars, and because of the availability of the primary allocation for Amateur Radio at 77.5-78 GHz and the secondary allocation for Amateur Radio in the remainder of the 77-81 GHz band.

36. Bosch is unconvinced, after several meetings with technical staff of ARRL, the national association for Amateur Radio, that there is any significant incompatibility between Amateur Radio and SRR operation at 79 GHz. The addition of vehicular radars in the 77-81 GHz band would not necessarily diminish the use of the primary 77.5-78 GHz allocation or the secondary 78-81 GHz allocation to the Amateur Service in the United States, and Bosch is unconcerned about interference from Amateur stations to SRRs. Amateur operations that are conducted in this frequency range tend to be largely experimental, occurring in geographic areas such as mountaintops and other rural areas where motor vehicle operation is not typical. Therefore, geographic separation will be

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71-76 GHz band, the Commission firmed up the allocation to the fixed, fixed-satellite (space-to-Earth), and mobile services on a primary basis. The 71-74 GHz band is additionally allocated to the mobile-satellite (space–to-Earth) on a primary basis; and the 74-76 GHz band is additionally allocated to the broadcasting and broadcasting-satellite services on a primary basis and to the space research service (space–to-Earth) on a secondary basis. All of those allocations were made available for both Federal and non-Federal Government use, except for the broadcasting and broadcasting-satellite service allocations, which were limited to non-Federal Government use.

[30] The Commission stated in Docket 02-146 that it was unclear whether the 75.5-76 GHz amateur radio band was being used at the time. Amateurs stated that there is documentary evidence of current use of 75 GHz and higher frequencies by amateur radio operators. However, the Commission found that amateur radio operators have access to the adjacent 77 GHz band, and there concluded that moving these operations out of the 75.5-76 GHz band would not pose a major inconvenience to amateur radio, but would benefit "future fixed services", because it would eliminate any possibility of harmful interference from amateurs. Accordingly, the primary allocations to the amateur and amateur-satellite services in the 75.5-76 GHz band were downgraded from primary to secondary status, and secondary use was to cease on January 1, 2006. This was codified in footnote US387 and in Section 97.303(r)(3) of the amateur service rules. *See, Allocations and Service Rules for the 71-76 GHz, 81-86 GHz, and 92-95 GHz bands*, Report and Order, 18 FCC Rcd. 23318 (2003).

typical and Amateur operation in the entire allocation at 77.5-81 GHz could continue without substantial fear of adverse interaction with vehicular radars.[31] Given the attenuation characteristics of this band discussed above; the downward inclination of SRR antennas on vehicles, the extensive frequency re-use opportunities, the low power used by SRRs, and the types of uses made by Amateur Radio operators in this band, it is suggested that there is no fundamental incompatibility between Amateur Radio operation at 77.5-81 GHz and SRR operation at 77-81 GHz. Bosch therefore proposes no change to the table of allocations and is satisfied that unlicensed SRRs can operate in the 79 GHz band without disruption of Amateur Radio operation, and without any significant risk of interference to SRR systems in operating motor vehicles. Bosch accepts the non-interference requirements relative to the Amateur Service that accompanies Part 15 unlicensed status, and the obligation to accept whatever interference may result from SRR deployment in the 79 GHz band.

37. That said, to the extent that there is any potential diminution of the utility of this band for radio Amateurs that might result from deployment of SRRs at 77-81 GHz, [32]

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[31] There is also a high degree of antenna decoupling. This was discussed in a 2004 ECC Report # 56 entitled "Compatibility of Automotive Collision Warning Short Range Radar Operating at 79 GHz With Radiocommunication Services" at page 19 thereof, the following was stated with respect to Amateur Radio operation in this frequency range:

> Antennas are in general mounted on masts as high as practical, high buildings, hills or mountaintops in order to obtain the least obstruction towards the horizon in order to make long distance contacts possible. The interaction with these carriers and the reflection from neighbouring obstacles or from other antennas mounted on the same carrier is case sensitive for each installation and has thus to be studied individually (no generic scenario definable).
>
> The mounting of antennas on high positions supports the assumption of a high decoupling factor to SRR's, which are installed on cars at a typical height of 50 cm over ground. Also SRRs are mounted to radiate horizontally, while the amateur receiver dishes are positioned high on top of buildings and hills for minimal obstruction towards the horizon.

[32] Anticipating that the agenda item dealing with the 77.5-78 GHz band at WRC-15 may affect the primary allocation for the Amateur Service in that range, it is a reasonable expectation that the Amateur Service should be reaccommodated elsewhere with an allocation that is no less useful than is 77.5-78 GHz now.

Bosch and the 79 GHz Project recommend that the Commission reinstate a domestic allocation for the Amateur Service at 75.5-76 GHz that will allow operation in an additional segment and will permit reaccommodation of any displaced Amateur Radio operators as the result of aggregate noise from SRRs in the 79 GHz band. Allowing United States radio amateurs to utilize the 75.5-76 GHz band will also harmonize the United States Amateur allocation with that in ITU Region 1 and in other areas of the world. This should promote international Amateur Radio experimentation and encourage the development of equipment for this band.

VII. Conclusions

38. The worldwide effort to harmonize the deployment of worldwide plan to consolidate automotive radars in the 76-81 GHz band is firmly established. The 79 GHz band provides an optimum frequency band for short-range automotive radars and a complement to the use of 76-77 GHz for long-range automotive radars operating pursuant to Section 15.253 of the Commission's Rules. Because frequency sharing between SRR systems and long-range automotive radars is not possible, the 79 GHz frequency range should be considered as the most suitable band for SRR worldwide. It provides optimum propagation characteristics and a very high degree of frequency re-use. The operating parameters for SRRs have been developed internationally as follows:

Frequency range of operation	77 to 81 GHz
Mean power spectral density (e.i.r.p.)	-3 dBm/MHz

As to spurious emission limitations, those outside the necessary bandwidth would be limited to a mean power spectral density (e.i.r.p.) below -30 dBm/MHz.

39. There is presently a shortage of available spectrum for vehicular radars in the United States. Making additional spectrum in the 79 GHz frequency range would have no significant impact on incumbent radio services with allocations at 77-81 GHz band, including the Amateur Radio Service; any non-vehicular Radiolocation uses; or passive Radioastronomy applications. Bosch proposes only the modification of Section 15.253 of the Commission's rules to permit the operation of vehicular radars to operate at 77-81 GHz on the same basis that vehicular radars are now operated in the United States at 76-77 GHz: on a non-allocated basis, premised on non-interference to licensed services, and on the acceptance of interference from allocated services in the band.

40. Automotive radar systems are exceptionally important to the public as safety devices. Statistics supporting that conclusion are highly compelling. The Commission's 2002 prediction when first permitting short-range vehicular radars at 24 GHz was correct: It expected "vehicular radar to become as essential to passenger safety as air bags for motor vehicles." New, automatic braking and other SRR systems now necessitate the use of the 79 GHz band in order to become ubiquitous and available to all motorists, not just those driving the most expensive vehicles.

41. Bosch and the 79 GHz Project are convinced of the compatibility of the proposed SRR use of the 79 GHz band with Radioastronomy and the Amateur Radio operators, as well as any other incumbent radiocommunication services. That said, Bosch and the 79 GHz Project members are committed to continuing to work in the private sector to develop compatible sharing protocols. The Commission should in any case reinstate the Amateur Service allocation domestically at 75.5-76 MHz in addition to retaining the Amateur primary allocation at 77.5-78 GHz and the secondary allocation at

78-81 GHz, so as to provide an accommodation for any future displaced Amateur operations and to internationally harmonize that allocation as well.

Therefore, the foregoing considered, Robert Bosch LLC respectfully requests that the Commission modify Section 15.253 of the Commission's Rules [47 C.F.R. §15.253] governing the operation of automotive radar systems in accordance with the attached Appendix.[33]

Respectfully submitted,

ROBERT BOSCH LLC

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April 27, 2012

[33] The attached Appendix is a modified version of the present Section 15.253 rule. However, in ET Docket 11-90, at the request of Toyota Motor Corporation, the Commission proposed to revise Section 15.253 in several respects, principally relative to the 76-77 GHz band automotive radars. See, *Amendment of Section 15.35 and 15.253 of the Commission's Rules Regarding Operation of Radar Systems in the 76-77 GHz Band,* Notice of Proposed Rule Making, 26 FCC 2d 8107 (2011). Bosch supports the changes to Section 15.253 proposed by Toyota Motor Corporation in that Docket proceeding and urges that any final rule modifications enacted pursuant to the instant Petition be consistent with those proposed in Docket 11-90.

APPENDIX

Section 15.253 of the Commission's Rules would be amended to read as follows:

§ 15.253 Operation within the bands 46.7–46.9 GHz, 76.0–77.0 GHz and 78.0-81.0 GHz.

(a) Operation within the bands 46.7-46.9 GHz and 76.0-77.0 GHz is restricted to vehicle-mounted field disturbance sensors used as vehicle radar systems. The transmission of additional information, such as data, is permitted provided the primary mode of operation is as a vehicle-mounted field disturbance sensor. Operation under the provisions of this section is not permitted on aircraft or satellites.

(b) The radiated emission limits within the bands 46.7-46.9 GHz and 76.0-77.0 GHz are as follows:

(1) If the vehicle is not in motion, the power density of any emission within the bands specified in this section shall not exceed 200 nW/ cm^2 at a distance of 3 meters from the exterior surface of the radiating structure.

(2) For forward-looking vehicle-mounted field disturbance sensors, if the vehicle is in motion the power density of any emission within the bands specified in this section shall not exceed 60 mW/ cm^2 at a distance of 3 meters from the exterior surface of the radiating structure.

(3) For side-looking or rear-looking vehicle-mounted field disturbance sensors, if the vehicle is in motion the power density of any emission within the bands specified in this section shall not exceed 30 mW/ cm^2 at a distance of 3 meters from the exterior surface of the radiating structure.

(c) Operation within the bands 76.0–77.0 GHz and 77.0-81 GHz is restricted to vehicle-mounted field disturbance sensors used as vehicle radar systems. The transmission of additional information, such as data, is permitted provided the primary mode of operation is as a ground-based vehicle-mounted field disturbance sensor. Operation under the provisions of this section is not permitted on aircraft or satellites.

1) The radiated emission limits within the bands 76.0–77.0 GHz and 77.0-81 GHz are as follows:

   (i) The average power density of any emission within the bands specified in this section shall not exceed 88 μW /cm^2 at a distance of 3 meters from the exterior surface of the radiating structure.

   (ii) The peak power density of any emission within the bands specified in this section shall not exceed 279 μW /cm^2 at a distance of 3 meters from the exterior surface of the radiating structure.

(d) The power density of any emissions outside the operating band shall consist solely of spurious emissions and shall not exceed the following:

(1) Radiated emissions below 40 GHz shall not exceed the general limits in § 15.209.

(2) Radiated emissions outside the operating band and between 40 GHz and 200 GHz shall not exceed the following:

(i) For vehicle-mounted field disturbance sensors operating in the band 46.7-46.9 GHz: 2 pW/ cm^2 at a distance of 3 meters from the exterior surface of the radiating structure.

(ii) For forward-looking vehicle-mounted field disturbance sensors operating in the bands 76-77 GHz or 77-81 GHz: 600 pW/ cm^2 at a distance of 3 meters from the exterior surface of the radiating structure.

(iii) For side-looking or rear-looking vehicle-mounted field disturbance sensors operating in the bands 76-77 GHz or 77-81 GHz: 300 pW/ cm^2 at a distance of 3 meters from the exterior surface of the radiating structure.

(3) For radiated emissions above 200 GHz from field disturbance sensors operating in the 76-77 GHz band: the power density of any emission shall not exceed 1000 pW/ cm^2 at a distance of 3 meters from the exterior surface of the radiating structure.

(4) For field disturbance sensors operating in the 76-77 GHz band, the spectrum shall be investigated up to 231 GHz.

(d) The provisions in § 15.35 limiting peak emissions apply.

(e) Fundamental emissions must be contained within the frequency bands specified in this section during all conditions of operation. Equipment is presumed to operate over the temperature range -20 to +50 degrees celsius with an input voltage variation of 85% to 115% of rated input voltage, unless justification is presented to demonstrate otherwise.

(f) Regardless of the power density levels permitted under this section, devices operating under the provisions of this section are subject to the radiofrequency radiation exposure requirements specified in § § 1.1307(b), 2.1091 and 2.1093 of this chapter, as appropriate. Applications for equipment authorization of devices operating under this section must contain a statement confirming compliance with these requirements for both fundamental emissions and unwanted emissions. Technical information showing the basis for this statement must be submitted to the Commission upon request.

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EXHIBIT A

ITU WRC15 AI 1.18

Allocation of the band 77.5-78 GHz to the radiolocation service to support automotive short-range high-resolution radar operations

The World Radiocommunication Conference (Geneva 2012),

considering

a) that the use of information and communication technologies (ICT) within intelligent transport systems (ITS), such as automotive short-range high-resolution radars (SRR), may significantly contribute to the improvement of road safety;

b) that the availability of spectrum for components of ITS such as SRR would contribute to the goal of improving road safety, including distracted driving, transport efficiency and the quality of the environment;

c) that ITU-R has been studying short-range vehicular radars;

d) that worldwide compatibility of spectrum allocation would be beneficial in terms of efficient use of spectrum and economies of scale, in order to give the automotive industry as well as the components industry the confidence to make substantial investment in SRR technology;

e) that the frequency bands 76-77.5 GHz and 78-81 GHz are already allocated to the radiolocation service on a primary basis in all three ITU Regions;

f) that the 77-81 GHz frequency band seems to be the most suitable band for SRR, since 76-77 GHz is designated for long-range automotive radars in many countries and sharing studies have concluded that sharing is not achievable between short-range and long-range automotive radars;

g) that the frequency band 77-81 GHz is already designated for SRR in many countries worldwide;

h) that the frequency band 77.5-78 GHz is allocated to the amateur and amateur-satellite services on a primary basis and to the radio astronomy service (RAS) and space research (space-to-Earth) service on a secondary basis;

i) that the aggregate effect of the automotive SRR must be considered;

j) that the 76-77.5 GHz and 79-81 GHz bands are allocated to the RAS on a primary basis, and the 77.5-79 GHz band is allocated to the RAS on a secondary basis;

k) that the 76-77.5 GHz and 78-81 GHz bands are allocated to the amateur, amateur-satellite and space research (space-to-Earth) services on a secondary basis;

l) that sharing with the radio astronomy service has been studied in some countries concluding that SRR operating in the vicinity of radio astronomy stations may cause interference to those stations, but that regulatory measures could be identified enabling coexistence between SRR and the radio astronomy service in the frequency band 77-81 GHz, which is dependent on the aggregated impact of SRR devices transmitting in the direction of a radio astronomy station;

m) that Resolution ITU-R 54-1 calls for studies to achieve harmonization for SRDs,

recognizing

ITU Council Resolution 1318 (Council 2010), on ITU's role in ICTs and improving road safety,

noting

a) that Recommendation ITU-R M.1890, on intelligent transport systems (ITS) – guidelines and objectives, provides general guidelines for ITS radiocommunication systems which covers also SRR;

b) that Recommendation ITU-R M.1452 provides guidance on the use of millimetre wave vehicular radar equipment and on technical characteristics of millimetre wave radiocommunication systems for data communications to be used for ITS;

c) that, while vehicular SRR is expected to contribute significantly to road safety, such applications have not been defined as a safety service according to No. **1.59** or subject to No. **4.10**,

resolves to invite WRC-15

to consider a primary allocation to the radiolocation service in the 77.5-78 GHz frequency band, taking into account the results of ITU-R studies,

invites ITU-R

to conduct, as a matter of urgency, and in time for consideration by WRC-15, the appropriate technical, operational and regulatory studies, including:

i) sharing studies and regulatory solutions to consider a primary allocation to the radiolocation service in the band 77.5-78 GHz, taking into account incumbent services and existing uses of the band;

ii) compatibility studies in the band 77.5-78 GHz with services operating in the adjacent bands 76-77.5 GHz and 78-81 GHz;

iii) spectrum requirements, operational characteristics and evaluation of ITS safety-related applications that would benefit from global or regional harmonization,

invites administrations

to contribute actively to ITU-R studies on this issue,

instructs the Secretary-General

to bring this Resolution to the attention of the international and regional organizations concerned, including ISO and the ITU's Collaboration on ITS Communication Standards.

EXHIBIT B

National Radio Astronomy Observatory

Electronics Division Technical Note No. 219

Measurements of Automotive Radar Emissions received by a Radio Astronomy Observatory

Darrel Emerson (National Radio Astronomy Observatory, Tucson, Arizona), Robert Freund (Arizona Radio Observatory, University of Arizona), Frank Gruson (Continental Corporation, A.D.C. Automotive Distance Control Systems GmbH, Germany), Juergen.Hildebrandt (Robert Bosch GmbH, Germany, 79 GHz Project Lead) and Alan Rogers (Haystack Observatory, M.I.T.)

December 8, 2011

Abstract

The radio astronomy community within the United States and elsewhere around the world enjoys a high degree of radio spectrum protection in the 77 to 81 GHz region. The global automotive industry, motivated by recent European Commission mandates, is developing short range radar systems to operate in this band to address issues of safety; the spectrum 76-77 GHz has already been in use since 1999 for Long Range Radars (Adaptive Cruise Control). In an attempt to understand the impact upon radio astronomy observations, measurements sponsored by the National Science Foundation were performed on 2 different short range vehicular radar systems. The radar systems were provided by Robert Bosch GmbH and by Continental Corporation and were operated at separation distances of 1.7 km and 26.9 km from the University of Arizona's 12 Meter millimeter wave telescope[1]. Measurements results are reported, and compared with the recommendations in ITU-R RA.769-2.

1 Introduction

Portions of the 76-81 GHz spectral region are allocated to the Radio Astronomy Service (RAS) in the United States and worldwide either on a primary or a secondary basis, and radio observatories that observe in this part of the spectrum currently enjoy interference-free operations. The worldwide automotive industry is developing various car radar systems for safety and operational purposes that would operate in this band on an unlicensed basis. In an effort to understand the impact that such systems may have on radio astronomy installations, measurements of the emissions of representative radar units were made at the University of Arizona's 12 Meter (12-M) Telescope[1] located at Kitt Peak, Arizona in October, 2011. Emissions of two different automotive radars, manufactured by Robert Bosch GmbH and by Continental Corporation were measured. These units were mounted temporarily on the vehicle; in production, they are expected to

[1] The 12-M Telescope at Kitt Peak is operated by the Arizona Radio Observatory (ARO) of Steward Observatory, at the University of Arizona.

be placed within a vehicle's bumper. The transmitters were first located at a nearby car park 1.7 km distant, and secondly at a site 26.9 km away at Sells, AZ. The 12-M telescope receiver was tuned to a center frequency of 79 GHz (Continental radar) or 77.8 GHz (Bosch radar). The car radars were used in an FMCW mode, in which the CW signal is swept at a constant rate from 77.03 to 78.58 GHz, a total bandwidth of 1550 MHz (Bosch radar) or from 78.93 to 79.1 GHz, a total bandwidth of 170 MHz (Continental radar).

The received signal was observed using the standard radio astronomical filter bank spectrometer covering a 500 MHz band centered at the radar's mid frequency, with 2 MHz resolution. In normal operation the 12-M Telescope uses a Cassegrain optics system. However, for this test we used the 12-M Telescope receiver and horn feed, but the beam of the feed was redirected from the subreflector by mounting a plane mirror in front of it . The main reflector of the 12-M Telescope thus did not play any part in these tests. With this arrangement the 12-M dish mount was used to point the beam of the telescope feed at the radar to achieve a "line of sight" path from the radar to the telescope receiver. Figure 1 shows the arrangement; a photograph of the plane reflecting mirror in front of the subreflector is shown in Figure 2. The redirected beam is offset by approximately 43.4 degrees in azimuth and 80 degrees in elevation away from the normal 12-M antenna pointing direction.

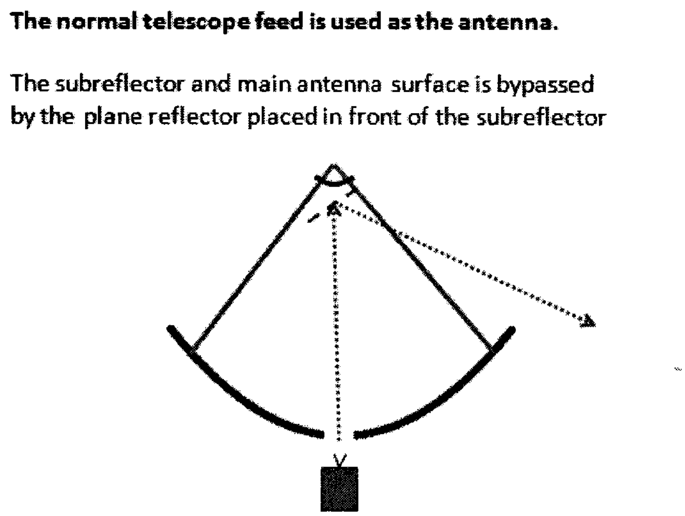

Figure 1 The normal secondary focus receiver and Cassegrain feed is used independently of the main 12-M reflector. An inclined plane reflector is placed in front of the subreflector, redirecting the beam from the receiver to the ground, rather than utilizing the main dish surface.

Figure 2 The inclined plane reflector in front of the subreflector redirects the signal received from the radar transmitter directly into the receiver, eliminating the use of the main antenna reflector. In the configuration shown, the signal is being received from the ground.

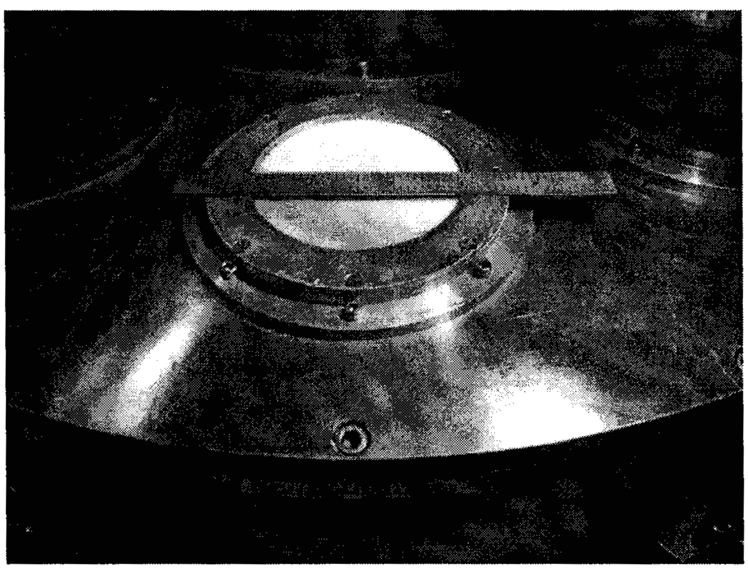

Figure 3 The 3-inch diameter window in the receiver Dewar is positioned immediately above the feed horn and SIS (superconductor-insulator-superconductor) mixer of the receiver used for these measurements. The signal is normally focused by the main 12-m diameter reflector onto the subreflector and then into the receiver. For these measurements, the signal from the radar is received directly, without utilizing the subreflector or the main 12-m antenna reflector at all.

The window above the SIS (superconductor-insulator-superconductor) mixer receiver in its Dewar is shown in Figure 3. The receiver itself is cooled to 4 K.
More details of the telescope's receiver optics can be found in the references below by Payne et al.

2 Beamwidth of the receiver feed

The beamwidth of the 12-M receiver feed was measured in a separate test in which the radar was located 1.7 km away in the parking lot of the 90" Steward Telescope (NB this is not a public parking area). With this line of sight path the radar signal was strong enough to easily determine the beamwidth in the vertical and horizontal directions by scanning the receiver beam across the radar source. The beamwidth was symmetrical in the vertical and horizontal directions with full-width half power of 3.1 +/- 0.1 degrees. Assuming a Gaussian beam this beamwidth corresponds to a gain of 35.8 +/- 0.2 dBi.

The main beam gain of a 12-M antenna, such as the mm-wave radio telescope at Kitt Peak, is about 78 dBi at 79 GHz, so the feed antenna used for these measurements is equivalent to a -42 dB sidelobe of such an antenna.

3 Receiver and system noise temperatures

The receiver noise temperature was calculated from the "Y factor" measurement using liquid nitrogen cooled absorber "cold" load (80K) and an absorber vane at ambient temperature (301K). The receiver noise temperatures were determined to be 75K and 108K respectively for the vertical (channel 1) and horizontal (channel 2) polarization channels of the receiver. For tests of the radar the system temperatures were assumed to be equal to the receiver noise plus the ambient temperature (301K) since the beam was always filled by the ground and atmospheric radiation when pointing at the radar; atmospheric attenuation over the 26.9 km path was some 4 dB, so atmosphere alone would have contributed some 180 K to the total receiver system noise over that path. We assume ground temperature and the atmospheric temperature over this near-horizontal path both equal to the ambient temperature.
A check of the receiving system was made by observing the Sun at an elevation of 10 degrees. This was the highest elevation at which the offset beam could be pointed and was reached with the 12-M dish mount pointed at the zenith. The "vane" calibrated temperatures measured on the sun were 167K and 170K respectively for the 2 channels. These values are close to the expected value of 168K above the atmosphere derived from the radio flux density of 10150.10^{-22} W/m^2/Hz at 79 GHz (see Benz, reference below). To first order the vane calibration measurement corrects for the attenuation of the atmosphere, so this is excellent agreement. These solar observations are completely consistent with the measured receiver temperatures and the feed antenna gain.

4 Beam polarizations

The receiver consists of two independent channels, sensitive to orthogonal linear polarizations. The two polarizations are split via a grid of parallel fine wires, which transmits one polarization and reflects the other. Allowing for the orientation of the plane mirror in front of the subreflector, one of these channels is sensitive only to vertical linear polarization, the other to horizontal. Tests of the polarization were made with the radar at 1.7 km. With the radar transmitting its normal vertical polarization mode, the signal was very strong in channel 1 and at least 30 dB weaker in channel 2. When the radar was physically rotated by 90 degrees the signal appeared in channel 2 and was more than 30 dB down in channel 1.

5 Measurements of the radar at 1.7 km

Figure 4 and Figure 5 show the signals received from, respectively, the Continental radar with a nominal 200-MHz bandwidth, and the Bosch radar with a nominal 1550-MHz bandwidth.

In Figure 4, the emission shows two distinct features

(a) A plateau of emission approximately 170 MHz wide, and

(b) A spike of emission at the high frequency end of the overall emission.

In both figures, the vertical axis is in units of antenna temperature, ultimately calibrated against the hot (ambient) and cold (liquid nitrogen) loads that had previously been measured in front of the receiver. For reference, 1000 K of antenna temperature, with a receiver antenna of gain 35.8 dBi, corresponds to an spfd (spectral power flux density) at the receiver of -115.0 dBW/m^2/MHz.

From Figure 4, the plateau of emission is 968 K, corresponding to an spfd at the receiver of -115.1 dBW/m^2/MHz. Integrating over the 170 MHz of emission, this becomes a power flux density (pfd) of -92.8 dBW/m^2 at the receiver. Allowing for a free space path and an atmospheric attenuation of 0.3 dB, this corresponds to a total emitted power (EIRP) at the transmitter, just within the plateau of emission, of +13.0 dBm. Expressing this as a spectral EIRP at the sensor, this is -9.3 dBm/MHz. This is in excellent agreement with the -9 dBm/MHz measured by the sensor manufacturer, and which represents the maximum power allowed by the European Norm EN 302 264.

The spike of emission in Figure 4 has a peak brightness temperature of 5982 K, as measured in a 2-MHz filter channel. Excluding the plateau of emission, that corresponds to a received spfd of -107.2 dBW/m^2/MHz. This spike of emission is only visible in this pre-series sensor and would be removed for the production version of the sensor. It is not considered further here.

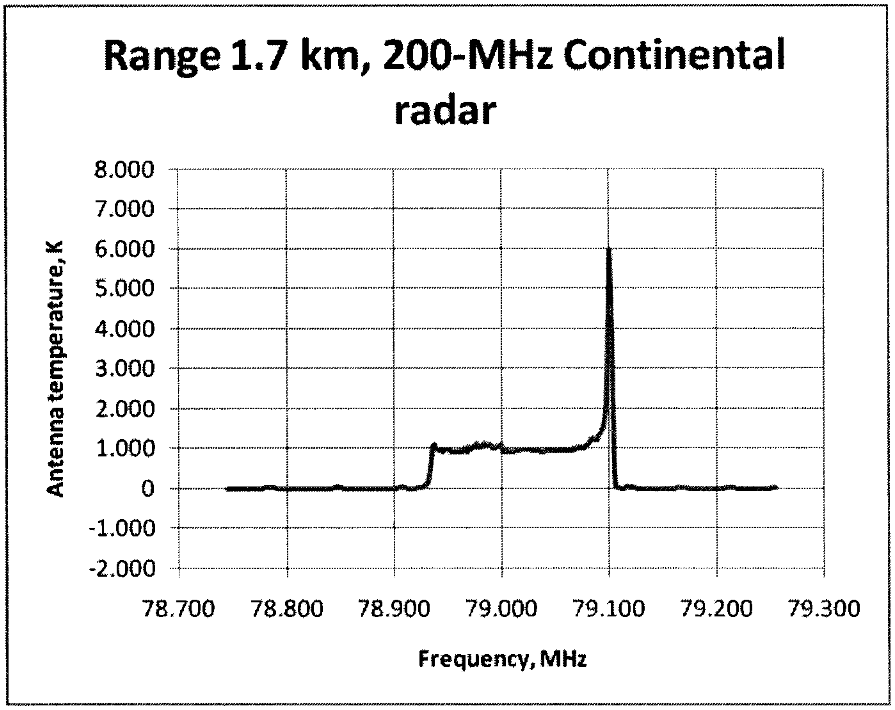

Figure 4 The received signal from the Continental radar, with a nominal 200-MHz bandwidth, at a distance of 1.7 km. See text for comments.

Away from the main emission of the transmitter, say +/-150 MHz in Figure 4, there is some residual response, but at a much lower amplitude of about 11 K. This is some 27 dB down on the peak emission of 5892 K. The theoretical rms receiver noise fluctuations for this observation are only ~0.084 K.

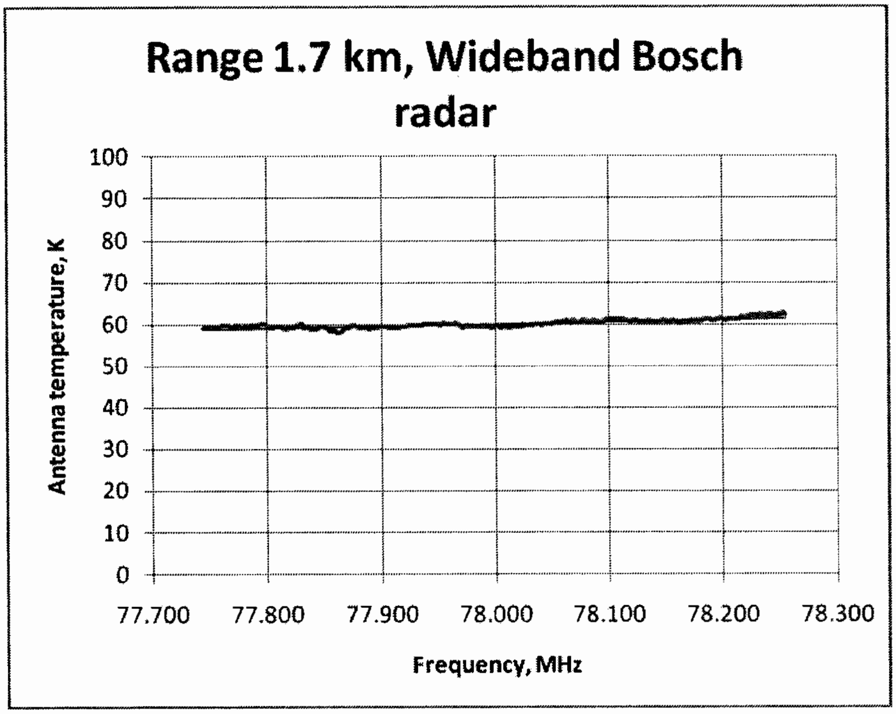

Figure 5 The signal received from the 1.7 km distant Bosch wideband radar, centered o n 77.8 GHz. Although the transmitted signal is nominally 1550 MHz wide, the receiver only sees the central 512 MHz of that band.

In Figure 5, showing the Bosch radar, the central 512 MHz of emission centered at 77.8 GHz, has a mean brightness temperature of 60.1 K. The corresponding spfd of this at the receiver is -127.2 dBW/m^2/MHz, with a received pfd (assuming 1550 MHz emission bandwidth) of -95.3 dBW/m^2. Again, allowing for the inverse square path loss and 0.3 dB of atmospheric attenuation, that corresponds to an effective isotropic radiated power (EIRP) of 13.7 dBm at the transmitter.

6 Measurement of the radar EIRP at 27 km.

The primary tests of the radar were made by driving to the seldom used airport at Sells, AZ. which is 26.9 km away and is in clear view of the 12-M telescope. The receiver beam was pointed at this location using angles computed from the GPS-determined locations of the radar at Sells and the 12-M telescope. After clearly detecting the radar in the spectrum of channel 1 the beam position was checked and found to be very close to the peak which was reached with a very small adjustment in elevation. The observed spectra are plotted in Figure 6 and Figure 7 in units of degrees Kelvin of antenna temperature. Each spectrum is the difference of the spectra taken for 30 seconds with the radar turned on followed by 30 seconds with the radar emission suppressed by covering its antenna with layers of absorber. This sequence may be repeated and the results averaged, in order to improve signal-to-noise ratio. The peak in the spectrum at 79.1 GHz, as already seen with the measurements at 1.7 km, is due to an initial low scan rate of the FMCW and is not expected in normal automobile radar operation. As before, the EIRP can be estimated from the integrated power over the 170 MHz width of the FMCW after correcting for the free space and atmospheric path loss and receiver antenna gain.

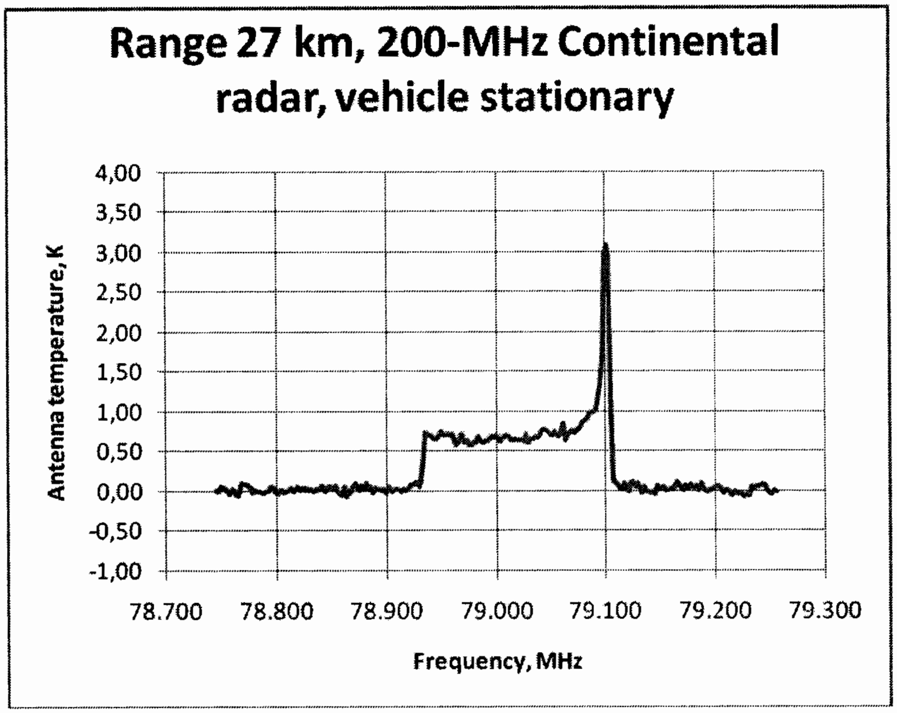

Figure 6 At a range of 26.9 km, this is the emission seen from the Continental 200-MHz radar, with the vehicle stationary. The average plateau of emission has a brightness of 0.68 K, while the high frequency spike is 3.08 K. The noise in the spectrum on either side of the emission is 0.038 K, close to the theoretical receiver noise of 0.036 K.

Figure 6, with the vehicle at 26.9 km and stationary, the received spfd of the plateau of emission is -146.7 dBW/m^2/Hz; the spike of emission is some 6.6 dB stronger. The received pfd of the plateau is -124.4 dBW/m^2. Allowing 99.6 dB for the free space path loss and 4 dB for atmospheric attenuation, the estimated EIRP of the plateau of emission is 9.2 dBm.

From Figure 7, with the vehicle in motion, the observed spfd of the plateau is -144.7 dBW/m^2/Hz, with the spike stronger by a similar factor. The received pfd of the plateau is -122.4 dBW/m^2, with an estimated EIRP for the plateau component of 11.2 dBm. While in motion, the antenna remained in an orientation facing the distant receiver. The received signal was averaged over 30 seconds.

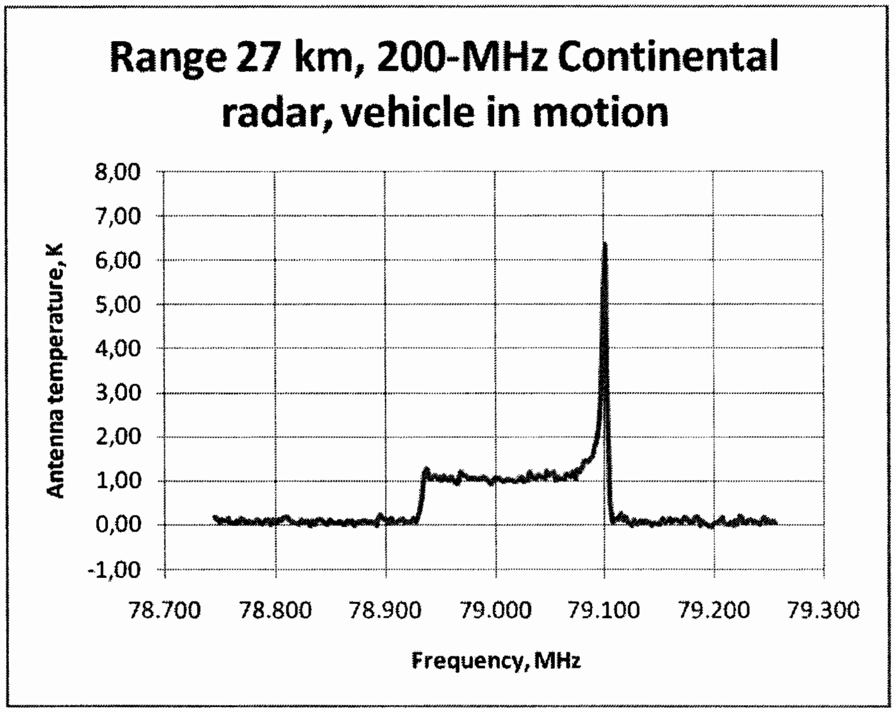

Figure 7 At a range of 26.9 km, the emission from the Continental 200-MHz radar, with the vehicle in motion. The plateau of emission has a brightness of 1.07 K, and the high frequency spike 6.4 K. The receiver noise on either side of the emission is 0.053 K, very close to the theoretical receiver noise of 0.049 K.

Figure 8 shows the observed emission from the 800-MHz Continental radar, with the vehicle in motion. The mean brightness of the observed emission at the range of 26.9 km is 0.41 K, although only the central 500 MHz of the 800-MHz spectrum are seen in the receiver. This corresponds to an observed spfd at the receiver of -148.8 dBW/m^2/MHz, with a pfd of -119.8 dBW/m^2. With the free space loss and 4 dB of atmospheric attenuation, this corresponds to an EIRP of 9.2 dBm.

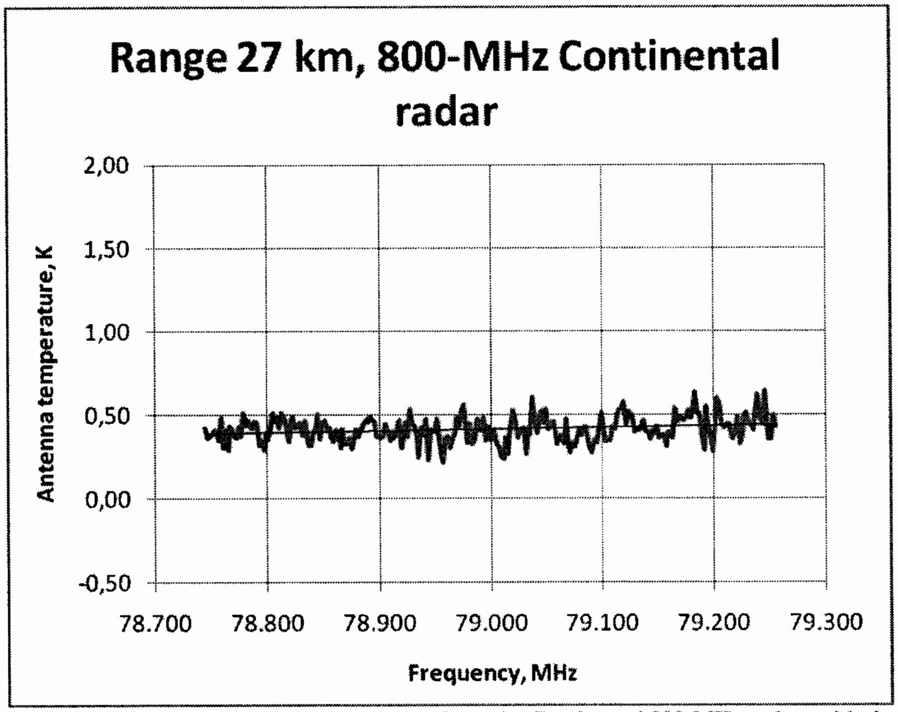

Figure 8 Range 26.9 km, observed emission from the Continental 800-MHz radar, with the vehicle in motion. The plateau of emission has a brightness of 0.41 K, although only the central 500 MHz of the 800 MHz emission spectrum are observed.

7 Summary of results

Table 1 Summary of Measurements

Fig	**Radar**	**Tb peak** K	**Tb plateau** K	**Prx** dBm	**Meas. Range** km	**Free space** loss dB	**Atm. Atten** dB	**Pfd** dBW/ m^2	**Spfd** dBW/ m^2/ MHz	**EIRP** dBm	**Avoid. Zone radius** km
4	Cont.200 Stationary	5982	968	-86.4	1.7	135.0	0.3	-92.8	-115.1	13.0	39
5	Bosch.WB Stationary	-----	60.1	-88.9	1.7	135.0	0.3	-95.3	-127.2	10.5	15
6	Cont.200 Stationary	3.08	0.68	-118.0	26.9	159.0	4.0	-124.4	-146.7	9.2	30
7	Cont.200 In motion	6.36	1.07	-116.0	26.9	159.0	4.0	-122.4	-144.7	11.2	34
8	Cont.WB In motion	-----	0.41	-113.4	26.9	159.0	4.0	-119.8	-148.9	13.7	25
-	**RA.769 1 MHz bw spectral line threshold**	-	-		-	-	-	-	**-148**	-	-